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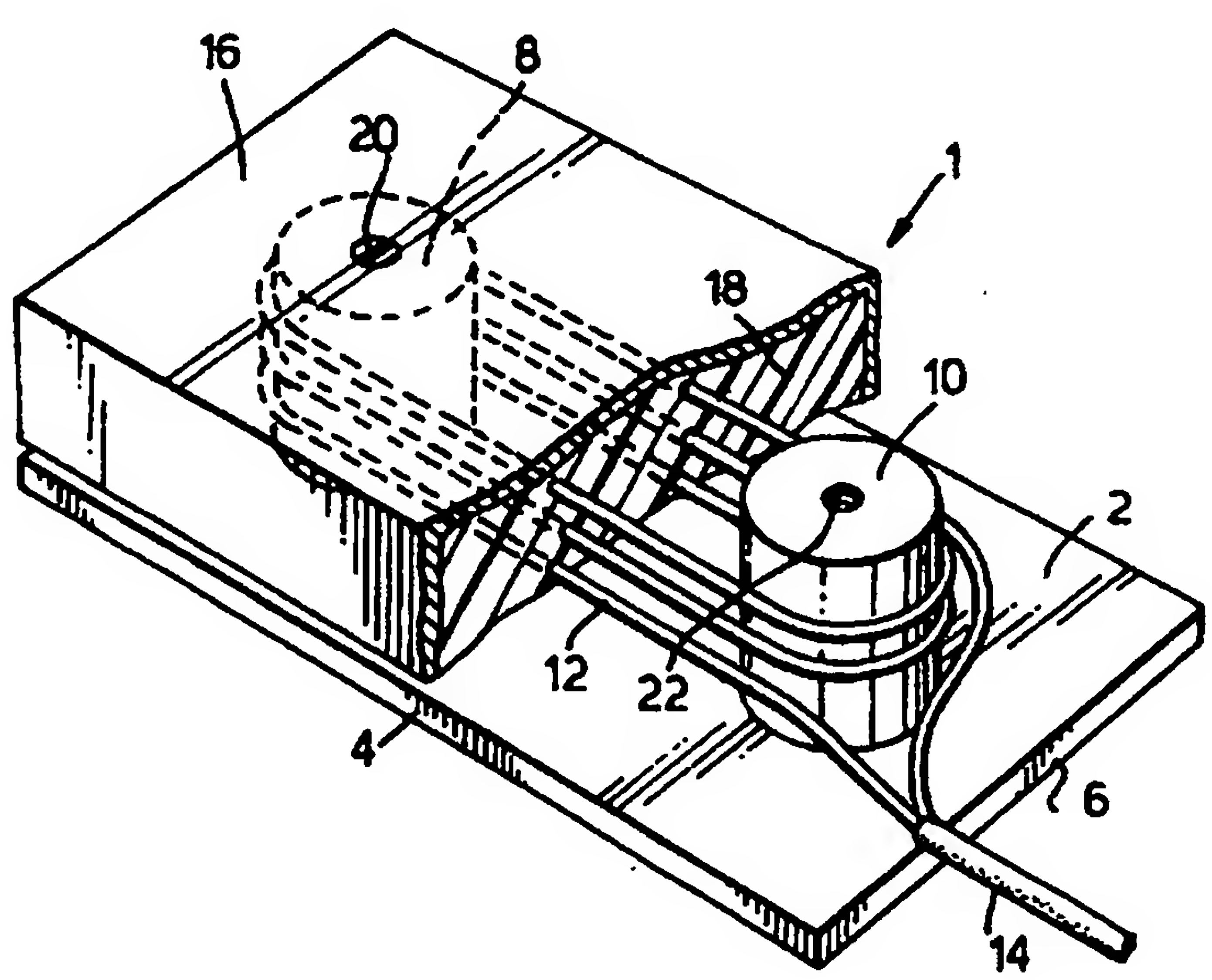

(57) Abstract

An optical fibre strain gauge (1) for an engineering structure e.g. a bridge, building, pipe, plant or the like, comprises: (a) a plurality of supports (8, 10) for the optical fibre that can be located on a surface of the structure and are spaced apart from one another over a part of the surface; and (b) at least one optical fibre (12) that is looped around the supports so that it extends between the supports, the optical fibre being fixed to the supports so that the length of the part of the fibre extending between the supports will vary in accordance with strain of the surface of the structure. The optical fibre(s) (12) can be looped around the supports (8, 10) a number of times, which enables the fibre(s) to be held more easily, and enables the strain gauge to incorporate a length of fibre significantly greater than the dimension of the area of the structure that is being monitored. The fibre(s) will normally contain reflectors such as Bragg gratings to enable signals to be monitored.

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STRAIN GAUGE

This invention relates to strain gauges for engineering structures e.g. bridges, buildings, pipes, plant and the like whether made from steel or concrete, and in particular to strain gauges that incorporate optical fibres as the strain sensing elements.

Strain gauges formed from optical fibres and having dimensions, in the order of 0.1 metre to 10 metres and especially in the order of 0.1 to 1 metre would be particularly useful in detecting and monitoring strain in large engineering structures. However, one significant problem in the use of optical fibres for such purposes is the issue of supporting the fibres on the structure so that the fibres are subjected to strains in the structure but without damaging the fibres or requiring costly and time-consuming methods of mounting the fibres on the surface of the structure.

According to the present invention, there is provided an optical fibre strain gauge for an engineering structure, which comprises:

a) a plurality of supports for the optical fibre that are, or can be, located on a surface of the structure and are spaced apart from one another over a part of the surface; and

b) at least one optical fibre that is looped around the supports so that it extends between the supports, the optical fibre being fixed to the supports so that the

length of the part of the fibre extending between the supports will vary in accordance with strain of the surface of the structure.

The strain gauge according to the invention has the advantage that the optical fibres can be looped around the supports a number of times. This enables the optical fibre or fibres to be held by the supports more easily so that the fibre or fibres are subject to the strain of the surface of the structure without the necessity of complex attachment procedures such as metallising and welding. In addition, the strain gauge according to the invention will incorporate a length of optical fibre that is significantly greater than the dimension of the area of the structure that is being monitored. This increases the flexibility of the design and enables, for example, areas of structures to be monitored which have dimensions smaller than the resolution of the equipment employed to monitor them.

The optical fibre or fibres will normally contain one or more reflectors so that light will be caused to pass in both directions along that part of the optical fibre extending between the supports. Thus, for example, the increase in length may be measured by a reflectometry method in which light is sent along the fibre and reflected back to a detector and changes in the length of the fibre alter the time taken before the light is detected at the detector. Such a detector may be formed by a mirror, a Bragg grating formed in the fibre, or even, in the broadest aspect of the invention, simply a cleaved end of the fibre. Such arrangements have the advantage that the reflector, and any additional elements that may be present, can be located at a position remote from the supports, so that if the structure to be monitored is subjected to very high temperatures or is otherwise located in a hostile environment, only that part of the or each optical fibre that is looped around the supports need be located in that environment. Alternatively the optical fibre may contain a strain-sensitive reflector such as a Bragg grating in that part of the fibre that extends between the supports. For example, in the case of a Bragg grating, the spacing of the grating will therefore vary in accordance with strain of the surface. Thus light of a broad wavelength spectrum could be launched into the optical fibre and the wavelength of the reflected light would vary in accordance with the strain of the surface. Instead, it may be appropriate to employ a Bragg grating whose grating

spacing varies along its length and to launch monochromatic light into the optical fibre. In this case the position along the optical fibre at which the grating spacing matches the light wavelength will vary with the strain on the surface and the path length of the light will change accordingly.

The optical fibre or optical fibres may simply be looped around the supports as a whole or they may additionally be wound around individual supports in a plurality of turns. This may enable the optical fibre or fibres to be held to the supports at least principally by friction, although it may be appropriate to provide some additional form of adhesion.

The or each optical fibre should be looped around the supports so that it is taut. However, in many cases it is preferred for the fibre to be under tension so that it is in a stretched state even when the structure surface is not strained. In this way the strain gauge will be able to record a degree of compressive strain in the structure surface as the separation between the supports decreases. Typically the optical fibre or fibres would be stretched to an elongation of 0.2 to 0.5% at zero structural strain.

The supports for the fibre may take any appropriate form, although it is preferred for them to comprise protuberances that extend from the surface of the structure and around which the or each optical fibre is looped. The supports preferably have no corners or edges that contact the optical fibre and which could cause light loss from the optical fibre by microbending. In addition the supports preferably have a curvature of radius of at least 30mm so that no light is lost from the fibre by macrobending. The supports may, for example, be formed as cylindrical protuberances of circular cross-section. However, in some circumstances it may be preferable for the protuberances to have lateral dimensions that diminish in a direction (normal to the surface) that extends away from the surface, for instance they may be frusto-conical in shape. Such forms of support can facilitate location of the optical fibre on them and removal of the optical fibre therefrom if the fibre is arranged in a capping element as explained below. In addition, such supports provide an easy method of stretching the optical fibre since, if the optical fibre is held in a loop, the loop of fibre will be stretched as it is pushed over the supports toward the surface of the structure.

In its simplest form of construction the strain gauge may have supports for the optical fibre that are formed integrally with the structure surface. However, it is preferred for the gauge to be formed separately from the structure so that it can be attached to the structure at any convenient time. For example, the supports may be located on a base plate that can be attached to the structure, for instance by welding or bolting.

The optical fibres may be looped around the supports by hand in situ, but it is preferred to package the optical fibres in a more rugged arrangement that will withstand normal abuse to be expected on a construction site and in use. For this reason the optical fibres may be provided in a capping element that is located on the supports. If the supports are frusto-conical or otherwise taper, the degree to which the capping element is pushed on to the supports will determine the degree to which the optical fibre is stretched as it is installed.

The strain gauge may include any appropriate number of supports. If it has two supports, the optical fibre will extend between the supports in one direction and will therefore detect strain in a single direction only. The strain gauge may alternatively include three or more supports arranged on the surface so that the optical fibre or fibres will be subject to strain occurring on the surface in two directions. For example they may be arranged to form the vertices of a triangle, preferably a right-angled triangle so that optical fibres extend over part of the surface in mutually perpendicular directions. It is possible for the strain gauge to have, for example, four supports arranged at corners of a rectangle, and for the optical fibre or optical fibres to extend between adjacent supports along the edges of the rectangle. In this case, if one of the supports is decoupled from the surface of the structure it will maintain a constant separation from the adjacent supports. Optical fibres extending along the edges of the rectangle that meet at that support will not be subject to strain of the surface of the structure and can be used for temperature compensation.

Several forms of strain gauge in accordance with the present invention will now be described by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a partially cut-away perspective view of one form of strain gauge;

Figure 2.is a schematic top view of a second form of strain gauge, and

Figure 3 is a schematic top view of a third form of strain gauge.

Referring to the accompanying drawings, figure 1 shows a strain gauge 1 which comprises a rectangular base plate 2 that can be firmly attached to a metal structure, for example, it can be welded to the structure along its edges 4 and 6 so that points on the base plate 2 follow strains on the underlying structure. A pair of protuberances 8 and 10 stand up from the base plate 2 and act as supports for an optical fibre strain sensing element of the strain gauge 1. The protuberances 8 and 10 are each frusto-conical in shape having a circular cross-section that is of minimum diameter of 60mm to prevent any light loss in the optical fibre by macrobending, and are each located at one end region of the base plate 2.

The strain gauge includes an optical fibre 12 that forms a strain sensing element, and is looped around the protuberances three times before being led away from the base plate 2 in a steel tube 14. Although only three loops of the optical fibre are shown for the sake of clarity, in practice the fibre may be looped around the protuberances many more times if desired, for example up to fifty or one hundred times. In addition the thickness of the optical fibre will be much less than as shown. The optical fibre may have a polymeric jacket formed, for example, from an acrylic polymer, and will typically meter (including jacket) of about 125μm. Alternatively the optical fibre may have a carbon coating or a metallic coating e.g. formed from aluminium or gold which will exhibit less creep, will give the fibre a higher degree of protection and will load to a reduced fibre diameter, thereby enabling a larger number of optical fibre loops if desired.

The protuberances 8 and 10 and the optical fibre 12 are enclosed in a steel capping element 16 that is also rectangular in shape and of substantially the same dimensions as the base plate 2. Apart from the protuberances 8 and 10 and the optical fibre 12, the interior of the capping element 16 is filled with a potting compound 18, for example polyurethane, a cured acrylic polymer or the like.

The strain sensor is manufactured and delivered to the installation site in two parts: the base plate with protuberances, and an assembly of the capping element 16 containing the optical fibre 12 and the potting compound 18. The capping element part

of the strain gauge is manufactured by looping the optical fibre 12 the required number of times around a former having the same shape and dimensions as the protuberances 8 and 10 or perhaps very slightly smaller diameters, placing the capping element over the former and optical fibre 12, filling the interior of the capping element 12 with the potting compound 18 and curing the potting compound. After the potting compound 18 has fully cured the former is removed.

In order to install the strain gauge, the base plate 2 is attached to the surface of the structure for example by welding, and the capping element assembly is pushed on to the two protuberances 8 and 10 sufficiently to cause the taper of the protuberances to stretch the optical fibre 12 by a small amount e.g. 0.2 to 0.5%. The appropriate degree of stretch of the optical fibre 12 may, for example, be ensured by providing one of the base plate or the capping element assembly with a stop and the capping element assembly may be forced on to the protuberances, for example by hammering, until further movement is prevented by the stop. The capping element 16 is retained on the base plate by means of screws 20 that are received by tapped holes 22 in the protuberances.

In use the length of the optical fibre will vary in accordance with changes in the separation of the protuberances 8 and 10, the total length of the fibre changing by 2n times the change in separation of the protuberances, where n is the number of times the optical fibre is looped around the protuberances. Appropriate choice of potting compound 18 and jacket material for the optical fibre 12 will cause adhesion between the two and will prevent or at least substantially reduce slippage of the fibre around the protuberances. Strain in the structure may be monitored by any of the following methods:

1) by providing a pair of reflectors such as Bragg gratings in the parts of the optical fibre remote from the strain gauge, and using reflectometry methods to monitor the change in the overall length of the optical fibre;

2) by providing Bragg gratings in the parts of the optical fibre that are subject to stretching and monitoring changes in wavelength of light reflected by the grating; or

3) by monitoring the variation of an intrinsic property of the fibre such as the propogation constant.

Figure 2 shows schematically a second form of strain gauge according to the invention which can monitor strain in two orthogonal directions A and B as shown in the drawing. The gauge is of the same construction as that of figure 1, and comprises a base plate 2 and three protuberances 8, 9 and 10, the protuberances subtending an angle of 90° about protuberance 9. Two separate optical fibres 12 and 12' are looped about protuberances 8 and 9 and about protuberances 9 and 10 respectively so that each optical fibre lies predominantly parallel to one of the directions A or B and predominantly perpendicular to the other of the directions.

Figure 3 shows schematically a third form of strain gauge according to the invention which can monitor strain in two orthogonal directions and is temperature compensated. The strain gauge is also of the same general construction as that shown in figure 1 but comprises a generally square base plate 2 having four protuberances 8, 9, 10 and 11, one protuberance in the region of each corner of the base plate 2. Four optical fibres 12, 12', 13 and 13' are wound around adjacent pairs of the protuberances so that each of the optical fibres extends generally along one edge of the base plate, optical fibres 12 and 13 being disposed along opposite parallel edges as are optical fibres 12' and 13'. The base plate is welded to the underlying structure surface by weld 20 which extends along two adjacent edges 21 and 22 of the base plate 2 but not along the other adjacent edges 23 and 24 (although the weld 20 could, if desired, be extended along part of the edges 23 and 24 in the region of protuberances 9 and 11). In this way, protuberances 8, 9 and 11 are fixed to the structure surface while protuberance 10 is decoupled from the surface and will maintain a constant separation from protuberances 9 and 11 other than due to variations in temperature. Optical fibres 12 and 12' will therefore act as strain sensing elements in respect of directions A and B respectively, while optical fibres 13 and 13' can be used to compensate for temperature effects

CLAIMS

1. An optical fibre strain gauge for an engineering structure, which comprises:

   a) a plurality of supports for the optical fibre that are, or can be, located on a surface of the structure and are spaced apart from one another over a part of the surface;

   b) at least one optical fibre that is looped around the supports so that it extends between the supports, the optical fibre being fixed to the supports so that the length of the part of the fibre extending between the supports will vary in accordance with strain of the surface of the structure.

2. A strain gauge as claimed in claim 1, wherein the optical fibre is looped around the supports a plurality of times so that the change in length of the optical fibre as a result of strain of the surface of the structure is greater than the change in separation of the supports.

3. A strain gauge as claimed in claim 1 or 2, wherein the optical fibre contains one or more reflectors so that light will be caused to pass in both directions along that part of the optical fibre extending between the supports.

4. A strain gauge as claimed in claim 3, wherein the or at least one of the reflectors is a Bragg grating.

5. A strain gauge as claimed in claim 4, wherein the optical fibre contains a Bragg grating in that part thereof that extends between the supports so that the grating spacing of the grating vary in accordance with strain of the surface.

6. A strain gauge as claimed in claim 3 or claim 4, wherein the or each reflector is located at a position remote from the supports.

7. A strain gauge as claimed in any one of claims 1 to 6, wherein the optical fibre is wound around each support in a plurality of turns.

8. A strain gauge as claimed in any one of claims 1 to 7, which includes at least three supports arranged on the surface so that the optical fibre or optical fibres will be subject to strain occurring on the surface in two directions.

9. A strain gauge as claimed in any one of claims 1 to 8, which includes four supports arranged at corners of a rectangle on the surface, and the optical fibre or optical fibres extend between adjacent supports along the edges of the rectangle, one of the supports being decoupled from the surface of the structure so that the part of the optical fibre or fibres extending along the edges of the rectangle that meet at that support will not be subject to strain of the surface of the structure.

10. A strain gauge as claimed in any one of claims 1 to 9, wherein the supports comprise protuberances that extend from the surface of the structure and around which the or each optical fibre is looped.

11. A strain gauge as claimed in claim 10, wherein the protuberances have lateral dimensions that diminish in a direction extending away from the surface.

12. A strain gauge as claimed in any one of claims 1 to 11, wherein the or at least one of the fibres is looped around the supports so that it is in a stretched state.

13. A strain gauge as claimed in any one of claims 1 to 12, wherein the supports are located on a base plate that can be attached to the surface of the structure.

14. A strain gauge as claimed in any one of claims 1 to 13, wherein the optical fibres are provided in a capping element that is located on the supports.

15 A strain gauge as claimed in claim 14, wherein the supports are in the form of protuberances that have lateral dimensions that diminish in a direction extending away from the surface, and the capping element has been pushed on to the protuberances so as to stretch the fibre or at least one of the fibres.

Fig.1.

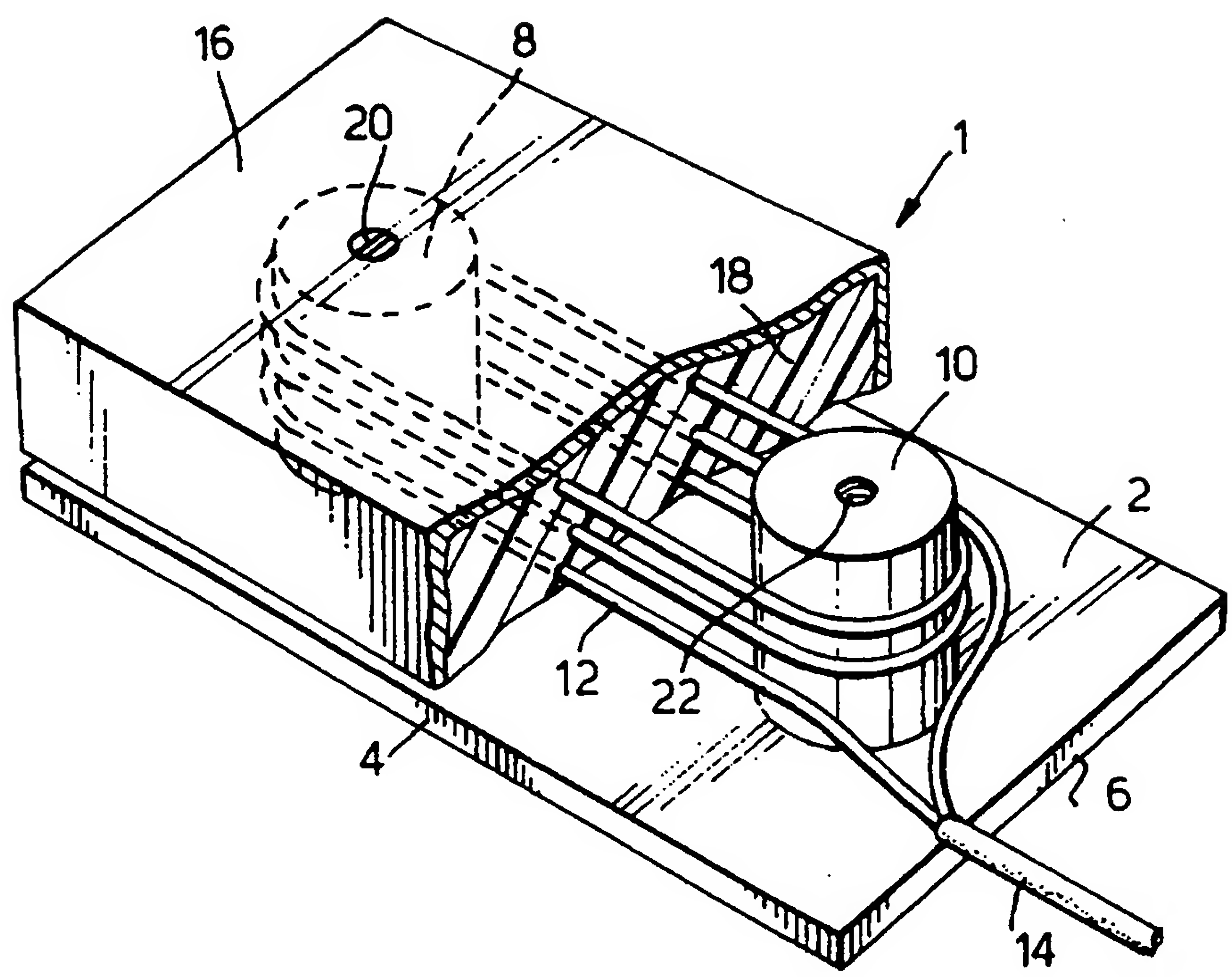


Fig.2.

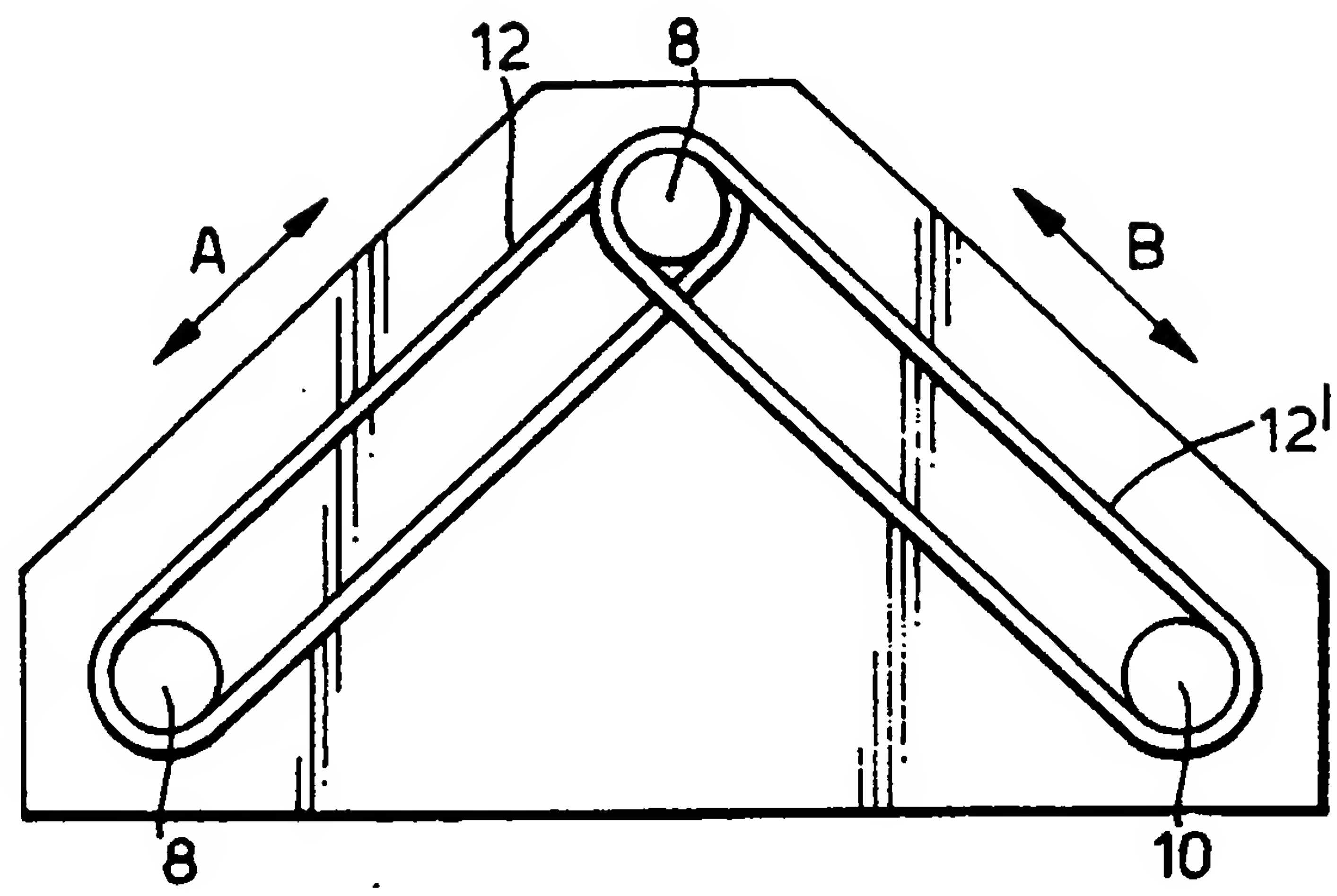
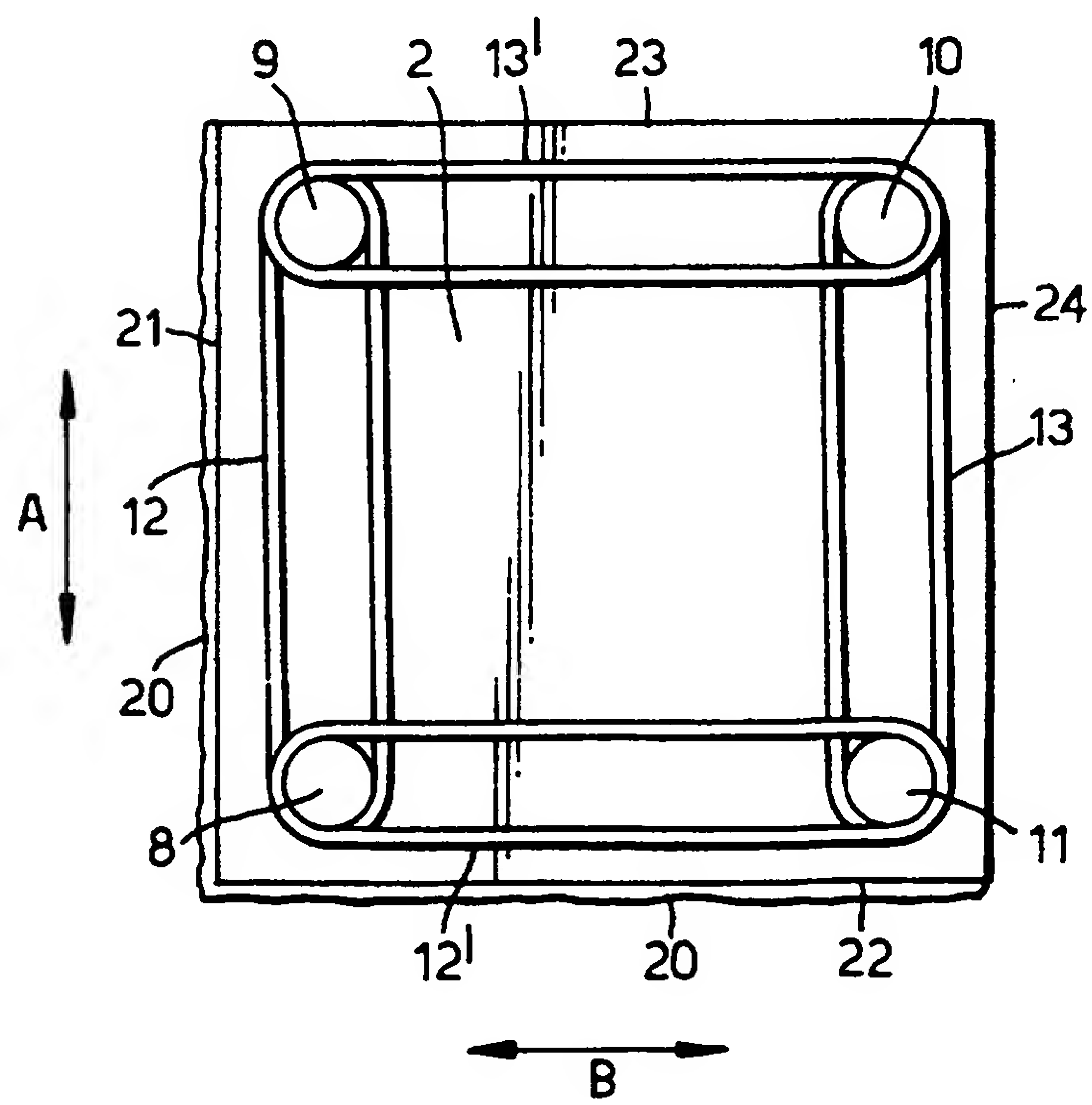


Fig.3.



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01B11/16 G01L1/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01B G01L G01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,4 671 659 (RAYMOND D. REMPT ET AL.) 9 June 1987 see abstract see column 3, line 17 - line 26; figure 1	1,2
Y		3-5
X	FR,A,2 707 754 (AEROSPATIALE SOCIETE NATIONALE INDUSTRIELLE) 20 January 1995 see abstract; figure 1	1
Y	EP,A,0 640 824 (BRITISH AEROSPACE PUBLIC LIMITED COMPANY) 1 March 1995 see column 2, line 45 - line 47 see column 2, line 54 - column 3, line 9 see column 3, line 33 - line 36; figure 2	3-5

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[X] Further documents are listed in the continuation of box C.

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INTERNATIONAL SEARCH REPORT

Inte nal Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US,A,5 250 802 (JACK A. RUNNER) 5 October 1993 see abstract; figure 1 -----	6

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